# STUDY ON THE EFFECT OF TEMPERATURE, HEATING RATE AND PARTICLE SIZE ON PALM OIL EMPTY FRUIT BUNCH (EFB) DECOMPOSITION RATE USING [illegible] METHOD

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CHEMICAL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JULY 2009

UNIVERSITI
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**Study on the Effect of Temperature, Heating Rate and Particle Size on Palm Oil Empty Fruit Bunch Decomposition using Taguchi Method**

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons.)
(Chemical Engineering)

JULY 2009

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# CERTIFICATION OF APPROVAL

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Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
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(CHEMICAL ENGINEERING)

Approved by,

____________________________________

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# CERTIFICATION OF ORIGINALITY

This is to certify that I, Halisa bt Mohd Said is responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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HALISA BT MOHD SAID

# ABSTRACT

Thermal decomposition of palm oil empty fruit bunch (EFB) was studied using thermal gravimetric analyzer (TGA). Effect of temperature, heating rate and sample particle size on EFB decomposition rate was investigated by analyzing the data obtained from TGA. The $L_9$ Taguchi method was used to design the experiment with three levels for each factor (heating rate: 10°C/min, 40°C/min, 100°C/min; temperature: 300°C, 500°C, 800°C and particle size: <125µm, 126µm-250µm, 251µm-500µm). The results obtained were then analyzed using analysis of variance (ANOVA) to know which parameter has the most significant effect on EFB decomposition. Percent contribution based on variance calculation shows that temperature with 56.867% percent contribution significantly affects EFB decomposition followed by heating rate of 36.323% percent contribution. Sample's particle size with percent contribution of 3.496% is the least significant parameter in the study.

# ACKNOWLEDGEMENT

The author wishes to take the opportunity to express her utmost gratitude to the individuals that had taken the time and effort to assist the author in completing the project. Without the cooperation of these individuals, no doubt the author would have faced some minor complications throughout the course. First and foremost the author's utmost gratitude goes to her supervisor, AP Dr Suzana bt Yusup for giving an opportunity for the author to work under her supervision in completing the studies. Without her guidance, encouragement and patience, the author would not be succeeded to complete the project. The author would like to express her gratitude to all the technician in Chemical and Mechanical Engineering Department, for assisting the author in conducting experiments. To all individuals who helped the author in any way, but whose name was not mentioned here, thank you all.

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## ABBREVIATIONS

| | |
|---|---|
| ANOVA | - Analysis of Variance |
| CO | - Carbon Monoxide |
| $CO_2$ | - Carbon Dioxide |
| DTG | - Differential Thermogram |
| EFB | - Empty Fruit Bunch |
| FTIR | - Fourier Transform Infrared |
| $H_2$ | - Hydrogen |
| TGA | - Thermogravimetric Analyzer |
| TG | - Thermogram |

# CHAPTER 1

# INTRODUCTION

## 1.1. Project Background

Nowadays, the world is struggling to find a new potential energy source to replace the dependency of fuels in the future. There are currently many sources of renewable energy such as solar, wind, geothermal and biomass. In a country that has significance amount of agricultural activities such as Malaysia, biomass is a promising alternative source of renewable energy. In fact, the government of Malaysia has embarked on the ideology by drafting the $5^{th}$ fuel policy that states *"To supplement the conventional energy supply, new sources such as renewable energy will be encouraged and biomass such as oil palm, wood waste as well as rice husk will be used on the wider basis."* [1]

## 1.2. Problem Statement

These renewable energy materials can be alternatively used for producing valuable chemical products such as fuel and chemical feedstock by applying the thermo-chemical conversion process like pyrolysis. Pyrolysis is a thermal decomposition process of biomass. There are several factors affecting pyrolysis including temperature, particle size, and heating rate [2]. The study of these factors on biomass decomposition is important in making biomass as the new potential renewable energy in the future.

### 1.3. Objective and Scope of Study

The main objective of this research project is to study the effect of temperature, heating rate and particle size in order to know which parameter have the most significant effect on EFB decomposition.

The experiments for this project were conducted based on Taguchi Method and analyzed using analysis of variance (ANOVA). The experiments were done using thermal gravimetric analyzer (TGA) where changes of sample's mass is monitored against time and temperature in the absence of oxygen at a specific heating rate. The results obtained are in the form thermogram (TG) and differential thermogram (DTG) curve.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Biomass Components

Biomass is a diverse and renewable resource, which can be exploited for the production of potential energy. Biomass is defined broadly as contemporary organic matter formed by photosynthetic capture of solar energy, which is stored as chemical energy.

The three main components of biomass are hemicellulose, cellulose and lignin and they in general cover respectively 20-40wt%, 40-60wt%, and 10-25wt% for lignocellulosic biomass such as palm oil waste (shell, EFB and fiber). Previous studies showed that biomass pyrolysis can be divided into four individual stages: moisture evolution, hemicellulose decomposition, cellulose decomposition and lignin decomposition. It was also suggested that the pyrolysis of any biomass can be considered as the superposition of the three main components [3]. The needs to study on the parameters that affects these components decomposition is important as it will affect the overall decomposition of the biomass itself.

### 2.1.1 Hemicellulose, Cellulose and Lignin.

Referring to [3], pyrolysis was done on the three main components of biomass (hemicelluloses, cellulose and lignin) in a TGA. The sample of ~10mg was heated up to 900°C at a constant heating rate of 10°C/min and kept for 3 minutes. Purified nitrogen was used at a flow rate of 120ml/min as a carrier gas to provide an inert atmosphere for pyrolysis and to remove the gaseous products, thus minimizing any secondary vapor-phase interactions. The results are shown in Table 1.

**Table 1:** Decomposition temperature and mass loss rate of hemicellulose, cellulose and lignin.

| Biomass Component | Decomposition Temperature Range (°C) | Max. Mass Loss Rate (wt%/°C) | Max. Mass Loss Rate Temperature (°C) | Solid Residue after 900 (wt%) |
|---|---|---|---|---|
| Hemicellulose | 220-315 | 0.95 | 268 | ~20 |
| Cellulose | 314-400 | 2.84 | 355 | ~6.5 |
| Lignin | ambient-900 | <0.14 | n/a | ~45.7 |

As observed from Table 1, at low temperature, hemicellulose is easiest component to decompose followed by cellulose and lignin. On the other hand, referring to the maximum mass loss rate, cellulose is the easiest and fastest component in biomass to decompose with less solid leftover.

Literature [3] also analyzed the components using FTIR by pelleting the sample with KBr powder. Hemicellulose consists of saccharides (xylose, mannose, glucose, galactose, etc), it appears a random, amorphous structure, rich of branches, which are very easy to remove from the main stem and to degrade into volatiles evolving (CO, $CO_2$, and some hydrocarbon) at low temperature. On the other hand, cellulose consists of a long polymer without branches; its structure is very strong. The thermal stability of cellulose is high. The higher IR absorbance of OH and C-O was found in cellulose while hemicellulose contained higher C=O compounds. Lignin is full of aromatic rings with various branches; the activity of chemical bonds in lignin covered an extremely wide range, which led to degradation of lignin in a wide temperature range (100°C - 900°C). Compared to both hemicellulose and cellulose, lignin was found to be rich with methoxyl-O-$CH_3$, C-O-C stretching and C=C stretching (aromatic rings) containing compounds.

## 2.2 Palm Oil Empty Fruit Bunch

Palm oil waste is the main biomass resource in ASEAN countries. Malaysia and Indonesia are the two largest palm oil producing countries in the world, where 30M ton and 8.2Mton of palm oil waste (such as EFB, fiber and palm oil shell) generated respectively in the year 2000, and they are increasing at spectacular pace with the rapidly expanding of food and manufacturing industries [2].

Literature [4] has done a study on pyrolysis of palm oil empty fruit bunch to form bio-oil. In conjunction with their studies, they have come out with properties of EFB table. The sample used was taken from Malaysia Palm Oil Board (MPOB).

**Table 2**: Properties of EFB (mass fraction, wt%)

| Component / Property | Literature Values | Measured | Method |
|---|---|---|---|
| Cellulose | 59.7, 38.1-42.0 | - | - |
| Hemicellulose | 22.1, 16.8-19.8 | - | - |
| Lignin | 18.2, 10.5-11.7 | - | - |
| **Elemental Analysis** | | | |
| Carbon | 48.9, 48.8, 49.2-50.6 | 49.07 | Elemental Analyzer |
| Hydrogen | 7.33, 6.3 | 6.48 | |
| Nitrogen | 0.0, 0.7, 0.78-1.19, 0.2, 0.8, 0.44 | 0.7 | |
| Sulphur | 0.68, 0.2 | <0.10 | |
| Oxygen | 40.2, 36.7 | 38.29 | By Difference |
| K | 2.41, 2.24 | 2 | Spectrometry |
| $K_2O$ | 3.08, 3.65 | - | - |
| **Proximate Analysis** | | | |
| Moisture | - | 7.95 | ASTM E871 |
| Volatiles | 87.3, 75.7 | 83.86 | ASTM E872 |
| Ash | 3.02, 7.3, 4.3 | 5.36 | NREL LAP005 |
| Fixed Carbin | 9.6, 17 | 10.78 | By difference |
| HHV (MJ/kg) | 19.0, 17.86, 15.5, <10 | 19.35 | Bomb Calorimeter |
| LHV (MJ/kg) | 17.2 | - | - |

From the research done on the MPOB EFB (Table 2), the composition of cellulose is the highest followed by hemicellulose and lignin.

## 2.3 Biomass Decomposition

There are several ways to make use of the energy contained in the biomass from old direct burning to gasification and pyrolysis. In this study, the decomposition rate of palm oil EFB is investigated through the sample's pyrolysis inside a TGA. Operating parameters such as heating rate, temperature and particle size are believed to significantly influence the pyrolysis of biomass [4]. The pyrolysis of biomass can be simplified by:

Biomass → $H_2$ + CO + $CO_2$ + hydrocarbon gas + tar + charcoal (endothermic)

### 2.3.1 Factors Affecting Biomass Decomposition

There are many factors affecting biomass decomposition, some of it are temperature, heating rate and particle size. Studies on the factors affecting biomass decomposition will help in further research of making biomass as the new potential energy source whether in solid, liquid or gaseous form.

#### *2.3.1.1 Temperature*

Temperature has been identified as an important reaction variable. So far, various experimental studies have investigated the influence of temperature on pyrolysis by evaluating the yields of different products as a function of temperature. In this study, the effect of temperature will be evaluated by the rate of EFB's decomposition by monitoring the mass loss of the sample in a TGA.

Literature [4] also studied the influence of temperature towards palm oil fiber pyrolysis. The yields of gas increased greatly with temperature, whereas the yield of char decreased sharply. This shows that the palm oil fiber has a high decomposition rate at higher temperature. An increase in reaction temperature is expected to enhance the extent of conversion of a biomass fuel to a gas product. The increases of dry gas yield and carbon conversion efficiency with temperature are due to increased production of gas during pyrolysis stage (endothermic process). Figure 1 shows the DTG curve of palm oil fiber pyrolysis at different temperature.

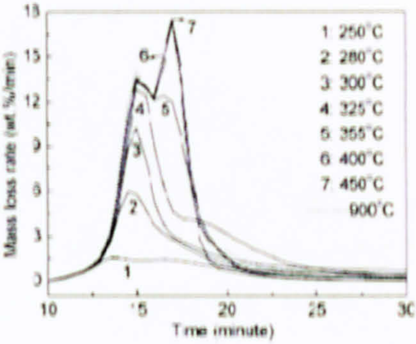
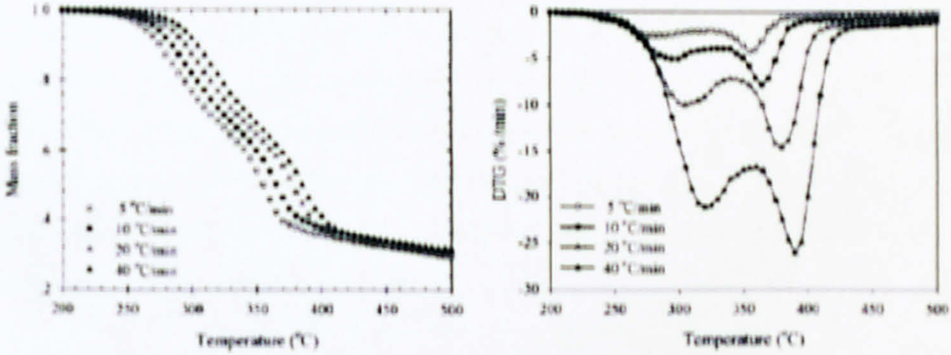



**Figure 1:** DTG curve of palm oil fiber at different temperature.

### *2.3.1.2 Heating Rate*

Literature [5] has done a study on oil palm fibre by pyrolyzing it in a TGA at various heating rate. The results showed that as the heating rate is increased, the TG curve shift systematically to higher temperature region as seen in Figure 2(a). The shift of TG curve to higher temperature region is due to the effect of heat transfer caused by the temperature lag between the surrounding and inside of the particle. The effect of heating rate can also be seen in DTG curve, Figure 2(b) where heating rate significantly affects on the maximum decomposition rate.




(a) TG Curve (b) DTG Curve

**Figure 2:** TG and DTG curve of palm oil fibre pyrolysis at different heating rate.

### *2.3.1.3 Particle Size*

An increasing in particle size can establish the temperature gradient, causing the increased of heat transfer resistance inside the pyrolyzed particles, which in turn causes an increase in the final solid yield and a decrease of volatile matter released during the pyrolysis process. [5]

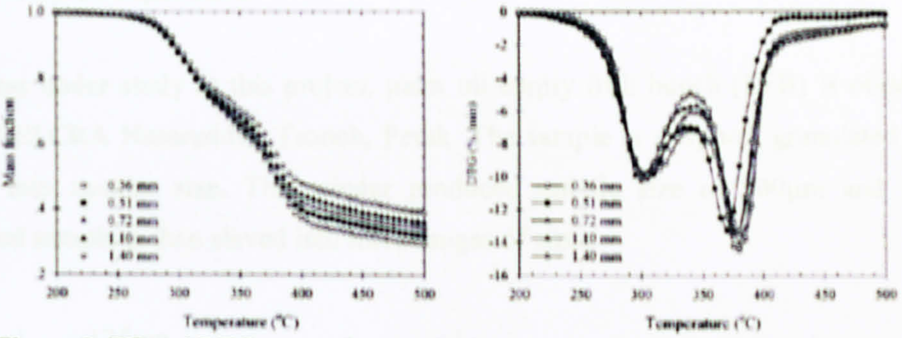



**Figure 3:** TG and DTG curve of palm oil shell pyrolysis at different particle size.

## 2.4 Thermogravimetric Analyser (TGA)

The experiments for this project were conducted in a TGA. The TGA used is a Perkin-Elmer, Pyris 1 model. It measures the changes in mass against temperature in the absence of oxygen at a specific heating rate. The results obtained are in the form of thermogram (TG) and differential thermogram (DTG) curve. The decomposition rate and behavior of palm oil EFB on the temperature, heating rate and particle size effects can be analyzed from the curve.

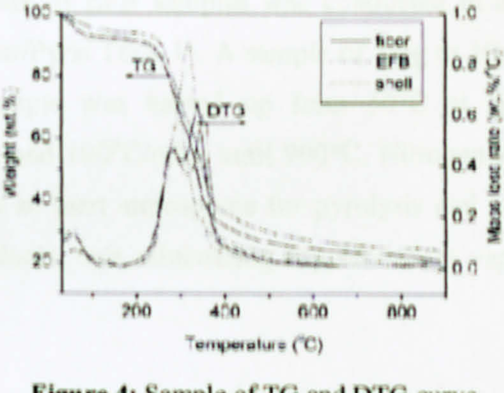



**Figure 4:** Sample of TG and DTG curve

# CHAPTER 3

# METHODOLOGY/PROJECT WORK

## 3.1 Procedure Identification

### 3.1.1 Sample Preparation

Biomass under study in this project, palm oil empty fruit bunch (EFB) is obtained from FELCRA Nasaruddin, Tronoh, Perak. The sample is chopped, granulated and grind into smaller size. The grinder produced sample size of 500μm and less. Grinded sample is then sieved into three ranges of sizes:

i. < 125μm
ii. 126μm – 250μm
iii. 251μm – 500μm

These samples are then heated in an oven at 110°C until the sample's moisture content is less than 10wt%. It were then stored in a plastic container for thermal gravimetric analysis.

### 3.1.2 Experimental Procedure

The decomposition rate of EFB samples was conducted in a thermal gravimetric analyzer (Perkin Elmer/Pyris TGA 1). A sample of 5mg to 10mg was used for each experiment. Each sample was heated up from 50°C at specified heating rate (10°C/min, 40°C/min and 100°C/min) until 900°C. Nitrogen is used as inert gas at 20mL/min to provide an inert atmosphere for pyrolysis and to remove the gaseous and condensable products, thus minimizing any secondary vapor-phase interactions during experiments.

## 3.2 Design of Experiments

### 3.2.1 Taguchi Method

The design of experiment implemented in this study case is Taguchi method. Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. It was developed by Dr. Genichi Taguchi of Japan. The experimental design proposed by Taguchi involves orthogonal arrays to organize the parameters affecting the process and the levels at which it should be varied. This allow the collection of necessary data to determine which factors most affects product quality with minimum amount of experimentation, thus saving time and cost. Taguchi Method not only help saving time and cost in doing the experiments, it also gives a valid results. [8]

#### *3.2.1.1 Orthogonal Array*

The set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. [8]

In this project, there are three parameters to be studied with three levels each. Using the array selector table, the best Taguchi orthogonal array to be used is selected as seen in Appendix A. Thus, the best way to do the experiments is by using $L_9$ orthogonal array.

**Table 3:** $L_9$ Orthogonal Array

| Experiment | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

The number 1, 2 and 3 in the column indicates the first, second and third value for the levels while P1, P2, P3 and P4 indicate the parameters to be used. The range is decided based on the literature review done.

#### *3.2.1.2 Conducting Experiments*

As stated above, the levels value of each parameter are decided based on the literature review done. Listed below are the values used in the experiments:

**Table 4:** Factors Value for Experiments

| Factor | A TEMPERATURE (°C) | B PARTICLE SIZE (μm) | C HEATING RATE (°C/min) |
|---|---|---|---|
| 1 | 300 | <125 | 10 |
| 2 | 500 | 126-250 | 40 |
| 3 | 800 | 251-500 | 100 |

**Table 5:** $L_9$ Array for Experiments

| EXPERIMENT | TEMPERATURE (°C) | PARTICLE SIZE (μm) | HEATING RATE (°C/min) | WEIGHT LOSS RATE (wt%/min) | |
|---|---|---|---|---|---|
| | | | | RUN 1 | RUN 2 |
| 1 | 300 | <125 | 10 | | |
| 2 | 300 | 126-250 | 40 | | |
| 3 | 300 | 251-500 | 100 | | |
| 4 | 500 | <125 | 40 | | |
| 5 | 500 | 126-250 | 100 | | |
| 6 | 500 | 251-500 | 10 | | |
| 7 | 800 | <125 | 100 | | |
| 8 | 800 | 126-250 | 10 | | |
| 9 | 800 | 251-500 | 40 | | |

### 3.3 Results Analysis Method

In Taguchi method, the results of experiments are analyzed to achieve one or more of the objectives below:

i. To establish the best or optimum condition for a product/process
ii. To estimate the contribution of individual factors (main effect)
iii. To estimate response under the optimum conditions

The objective of the study is to know which of the three parameters (temperature, particle size and heating rate) significantly affect EFB decomposition (ii). In order to achieve the objective, ANOVA is used as analysis method. [9]

#### 3.3.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is applied to the results of experiments in order to determine the percent contribution of each factor by calculating the variance. Study of ANOVA helps to determine which of the factors need control and which do not. This is also known as "main effect" [9]. ANOVA calculations in this study are based on the steps done in literature [10].

##### *3.3.1.1 Computation of Average Performance*

In computing the average performance of the factor A, level 1 ($A_1$) occurs in experiment numbers 1, 2 and 3. The average effect of $A_1$ is therefore calculated by using this equation:

$$A_{1(avg)} = \frac{Y_1 + Y_2}{2} \qquad (1)$$

$Y_1$ and $Y_2$ are the results obtained from for factor $A_1$. The same goes to other factors.

#### *3.3.1.2 Quality Characteristics*

Quality characteristics are described as:

i. Bigger is better
ii. Smaller is better
iii. Nominal is better

In this study, bigger is better as the quality characteristics where bigger rate of decomposition is desired.

#### *3.3.1.3 Results observation and S/N Ratio*

When experiments involve multiple runs, Taguchi approach uses signal-to-noise ratio (S/N) as a performance measure. S/N ratio table is developed by computing the S/N value for each run. Since bigger is better quality characteristic is used, the S/N value is calculated using:

$$S/N = -10 \log_{10} (MSD) \quad (2)$$

$$MSD = \frac{1}{n} (Y_1 + Y_2) \quad (3)$$

MSD is mean squared deviation which is a statistical quantity that reflects the deviation from target value.

*3.3.1.4 ANOVA*

*3.3.1.4.1 Sum of Squares (SS)*

Sum of square (SS) is a measure of the deviation of the experimental data from the mean value of the data. It is calculated as follows:

1. Correlation Factor (CF):

$$CF = \frac{\sum T^2}{N} \tag{4}$$

Where, T : Total S/N of factor A, level 1 ($A_1$)

N : Total number of experiments (in $L_9$, N = 9)

2. Total Sum of Square ($SS_T$)

$$SS_T = \sum_{j=1}^{N} y_j^2 - CF \tag{5}$$

Where, $y_j$ : S/N of experiment j

3. Sum of Square of Factor i ($SS_i$):

$$SS_i = \sum_{k=1}^{3} \frac{y^2_{ik}}{N_{ik}} - CF \tag{6}$$

Where , $y^2_{ik}$ : The total of S/N for factor *i* at level *k*

$N_{ik}$ : Number of S/N with factor *i* at level *k* in orthogonal array

4. Sum of Squares for Error ($SS_e$):

$$SS_e = SS_T - \sum_{i=1}^{N} SS_i \tag{7}$$

#### 3.3.1.4.2 *Degree of Freedom (DOF):*

Degree of freedom is a measure of the amount of information that can be uniquely determined from a given set of data. DOF for data is a factor equals to one less than number of levels.

1. Degree of freedom of factor $i$ ($Df_i$) :

$$Df_i = L - 1 \tag{8}$$

Where, L : Level of factors (in this study, L = 3)

2. Total degree of freedom for an experiment ($Df_T$):

$$Df_T = N - 1 \tag{9}$$

3. Degree of freedom for error ($Df_e$):

$$Df_e = Df_T - \sum_{i=1}^{N} Df_i \tag{10}$$

#### 3.3.1.4.3 *Variance (V)*

Variance of each factor is determined by the sum of squares divided by degree of freedom. It is used in the evaluation of significance of the factor effects on the response.

1. Variance for factor $i$ ($V_i$):

$$V_i = \frac{SS_i}{Df_i} \tag{11}$$

2. Variance for error ($V_e$):

$$V_e = \frac{SSe}{Df_i} \tag{12}$$

*3.3.1.4.4 Variance Ratio (F)*

Variance ratio, commonly called F-statistic, is the ratio of variance due to the effect of a factor ad variance due to error term. It is used to measure the significance of the factor under investigation with respect to the variance of all the factors included in the error term.

$$F_i = \frac{SSi}{SS_e} \tag{13}$$

*3.3.1.4.5 Pure Sum of Squares (SS')*

$$SS'_i = SS_i - V_e \, . \, Df_i \tag{14}$$

*3.3.1.4.6 Percent Contribution (P)*

The percent contribution for any factor is obtained by dividing the pre sum of squares (SS') for that factor by total sum of squares ($SS_T$) and multiplying the result by 100.

$$P_i = \frac{SS'i}{SS_T} \tag{15}$$

The calculations above can be summarized with ANOVA table as shown in Table 6 below.

**Table 6:** ANOVA Table

| FACTOR | WEIGHT LOSS RATE CONVERSION | | | | | |
|---|---|---|---|---|---|---|
| | Sum of Square (SS) | Degree of Freedom (DOF) | Variance (V) | Variance Ratio (F) | Pure Sum of Square (SS') | Percent Contribution (P) |
| Temperature (A) | | | | | | |
| Particle Size (B) | | | | | | |
| Heating Rate ( C) | | | | | | |
| Error | | | | | | |
| Total | | | | | | |

The most significant parameter affecting EFB decomposition can be obtained by looking at the highest percent contribution of the factor.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 EFB Decomposition Behavior

Thermal decomposition of oil palm empty fruit bunch (EFB) was done at three different heating rates of 10°C/min, 40°C/min and 100°C/min for three range of particle size of <125μm, 126μm-250μm and 251μm-500μm. The experiments were done to investigate which parameter has the main effect on EFB decomposition. Figure 5 below shows a typical TG curve of palm oil EFB decomposition.

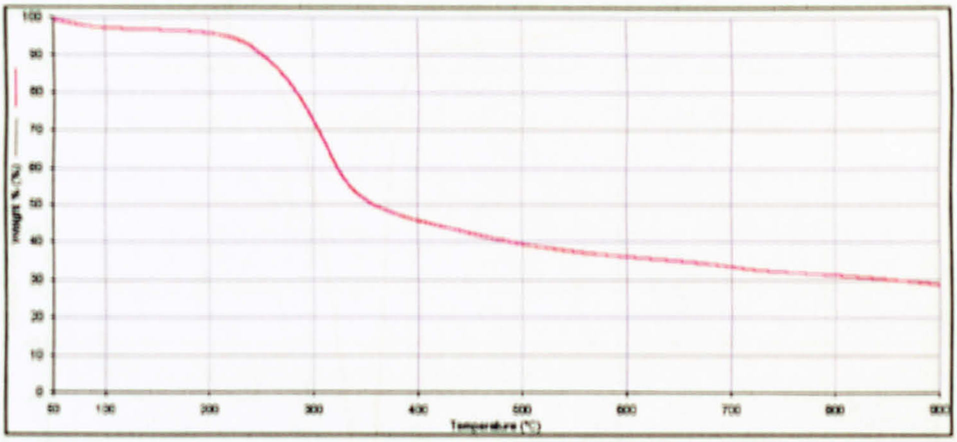


**Figure 5:** TG Curve - General Profile of EFB Decomposition

As seen in Figure 5, temperature increment from 50°C to 100°C resulted in slight weight loss due to loss of moisture contained in the sample. It is known that the three main components in oil palm EFB are cellulose, hemicellulose and lignin. Based on literature reviews done, lignin is known to be the first component to decompose at a lower temperature with a low decomposition rate. The range of temperature of lignin decomposition is from 150°C to 900°C. This occurs right after the moisture loss section. The weight slowly decreases since the lignin decomposition has a slow rate and with the lowest composition of 10wt%.

From Figure 5 above, it can be seen that the main thermal decomposition of EFB occurred at temperature range from 200°C to 400°C. This is where hemicellulose and cellulose decomposition took place. These two are the main components in EFB. Hemicellulose decompose is mainly at 200°C to 315°C with the composition covers up to 20wt%. It was then followed by cellulose where the decomposition occurs at a higher temperature of 315°C to 400°C. Even though it decomposes at such a higher temperature, it is the easiest component to decompose followed by hemicellulose and lignin. Moreover, it has the higher composition of 40wt%. Observations were made based on literature review.

## 4.2 EFB Decomposition Rate Profile

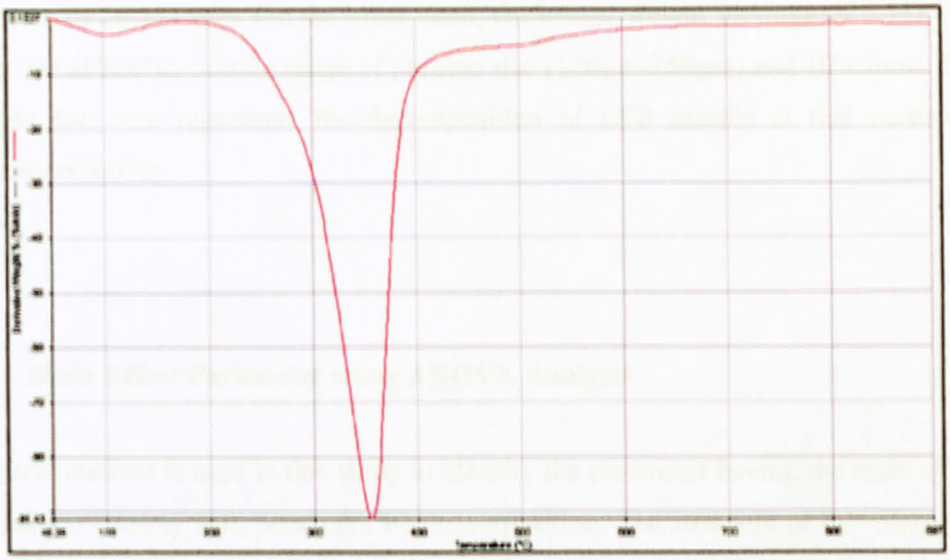


**Figure 6:** DTG Curve - General EFB Decomposition

Figure 6 shows a DTG curve of EFB decomposition. DTG curve shows the weight loss rate of each experiment. The Y-axis represents the weight loss rate. The negative indicates decrement of weight over time.

**Table 7**: Results of Experiments

| EXPERIMENT | TEMPERATURE (°C) | PARTICLE SIZE (μm) | HEATING RATE (°C/min) | WEIGHT LOSS RATE (wt%/min) | | |
|---|---|---|---|---|---|---|
| | | | | RUN 1 | RUN 2 | AVERAGE |
| 1 | 300 | <125 | 10 | 4.927 | 5.232 | 5.080 |
| 2 | 300 | 126-250 | 40 | 13.652 | 15.144 | 14.398 |
| 3 | 300 | 251-500 | 100 | 24.443 | 28.271 | 26.357 |
| 4 | 500 | <125 | 40 | 2.349 | 2.246 | 2.297 |
| 5 | 500 | 126-250 | 100 | 4.920 | 5.149 | 5.035 |
| 6 | 500 | 251-500 | 10 | 0.395 | 0.386 | 0.391 |
| 7 | 800 | <125 | 100 | 3.140 | 5.565 | 4.353 |
| 8 | 800 | 126-250 | 10 | 0.115 | 0.148 | 0.131 |
| 9 | 800 | 251-500 | 40 | 0.381 | 0.306 | 0.343 |

As seen in Table 8, experiment 3, with temperature of 300°C, middle range of particle size (126μm-250μm) and heating rate of 100°C/min have the highest weight loss rate of 26.357wt%. On the other hand, the lowest weight loss rate of 0.131wt% occurred at 800°C, middle range of particle size (126μm-250μm) and 10°C/min. The weight loss rate represents the decomposition of EFB sample at that particular parameter setting.

## 4.3 Main Effect Parameter using ANOVA Analysis

Taguchi method is used in this study to identify the parameter having the main effect on palm oil empty fruit bunch (EFB) decomposition. The structure of $L_9$ orthogonal array design and results of EFB decomposition rate is shown in Table 9. In this study, analysis of variance (ANOVA) method is used to analyze the results obtained. ANOVA is a standard statistical technique which routinely used to identify the parameter that significantly affect the quality characteristic, in this case is the decomposition rate.

**Table 8:** ANOVA Analysis Results

| FACTOR | WEIGHT LOSS RATE CONVERSION | | | | | |
|---|---|---|---|---|---|---|
| | Sum of Square (SS) | Degree of Freedom (DOF) | Variance (V) | Variance Ratio (F) | Pure Sum of Square (SS') | Percent Contribution (P, %) |
| Temperature (A) | 1127.963 | 2.000 | 563.981 | 69.619 | 1111.761 | 56.867 |
| Particle Size (B) | 84.540 | 2.000 | 42.270 | 5.218 | 68.338 | 3.496 |
| Heating Rate ( C) | 726.319 | 2.000 | 363.159 | 44.829 | 710.117 | 36.323 |
| Error | 16.202 | 2.000 | 8.101 | | | 3.315 |
| Total | 1955.023 | 8.000 | 244.378 | | | 100.000 |

The significant parameter affecting EFB decomposition is the one with the highest percent contribution based on variance calculation. The results of ANOVA show that temperature (P=56.867%) is the most significant parameter affecting EFB decomposition followed by heating rate (P=36.323%) and particle size (P=3.496%). The optimum level can be obtained by further studies on S/N ratio analysis which is not covered in this study.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Effect of temperature, heating rate and particle size of palm oil empty fruit bunch decomposition rate is studied using TGA based on Taguchi method. The results from TGA were analyzed using ANOVA to know the main effect (significant parameter) on EFB decomposition.

TGA produced thermogram (TG) and differential thermogram (DTG) curve. TG curve represents decomposition behavior of EFB. It was found that EFB decompose similarly to other palm oil waste. Based on TG curve obtained, the main decomposition occurred from 200°C to 400°C. The decomposition rate of EFB can be obtained from DTG curve which are the results used in analysis.

ANOVA analysis is done. It was found that the most significant parameter affecting EFB decomposition is temperature with 56.867% percent contribution, followed by heating rate of 36.323% percent contribution. Sample's particle size with percent contribution of 3.496% is the least significant parameter in the study.

## 5.2 Recommendations

Some recommendations need to be done in order to improve the study on palm oil EFB decomposition. It is recommended to conduct S/N ratio analysis in order to know the optimum operating level for EFB decomposition. Confirmation test should be done on the S/N ratio results. The combination of ANOVA, S/N ratio analysis and confirmation test will give a solid founding on the effect of temperature, heating rate and particle size on EFB decomposition. These improvements will help in making EFB as the future potential renewable energy source as palm oil has a big potential in Malaysia.

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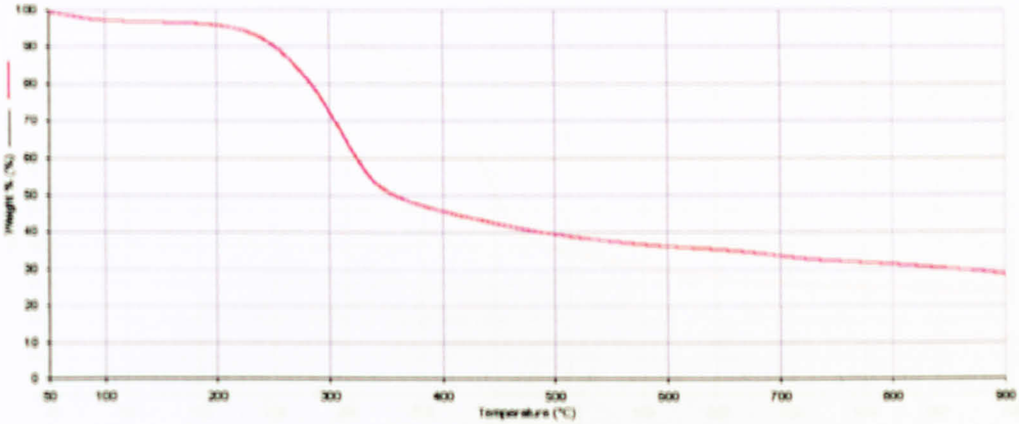
# APPENDICES

### *Appendix A: Taguchi's Orthogonal Array Selector*

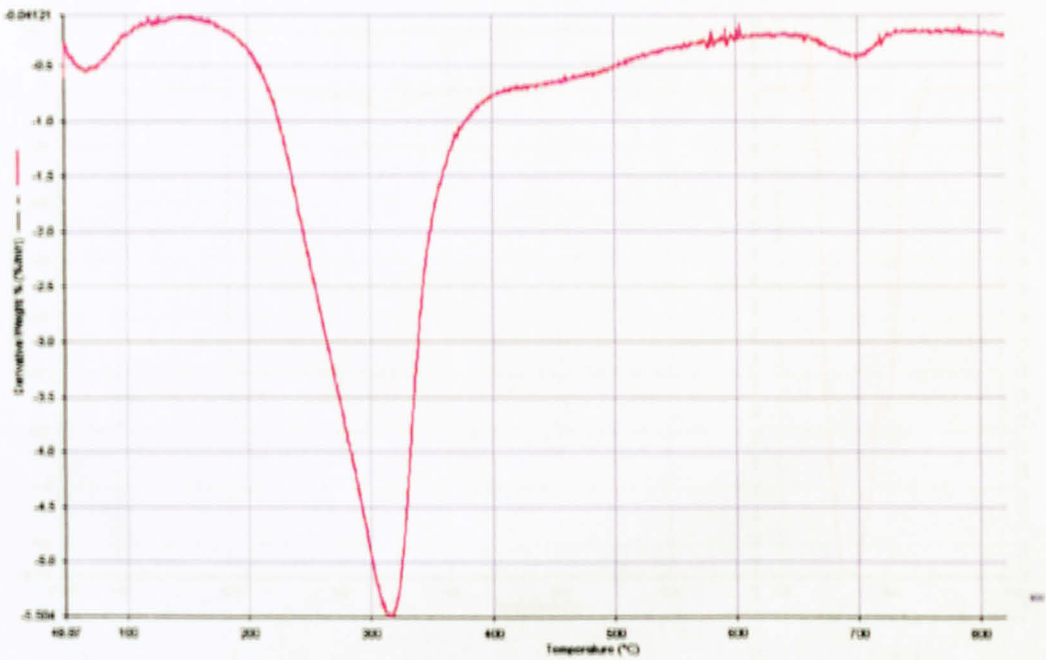
| | | Number of Parameters (P) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **Number of Levels** | **2** | L4 | L4 | L8 | L8 | L8 | L8 | L12 | L12 | L12 | L12 | L16 | L16 | L16 | L16 | L32 |
| | **3** | L9 | L9 | L9 | L18 | L18 | L18 | L18 | L27 | L27 | L27 | L27 | L27 | L36 | L36 | L36 |
| | **4** | L16 | L16 | L16 | L16 | L32 | L32 | L32 | L32 | L32 | | | | | | |
| | **5** | L25 | L25 | L25 | L25 | L50 | L50 | L50 | L50 | L50 | L50 | L50 | | | | |

| | | Number of Parameters (P) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** |
| **Number of Levels** | **2** | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 | L32 |
| | **3** | L36 | L36 | L36 | L36 | L36 | L36 | L36 | | | | | | | | |
| | **4** | | | | | | | | | | | | | | | |
| | **5** | | | | | | | | | | | | | | | |

## B.1 Experiment 1 (<125μm - 10°C/min - 300°C)

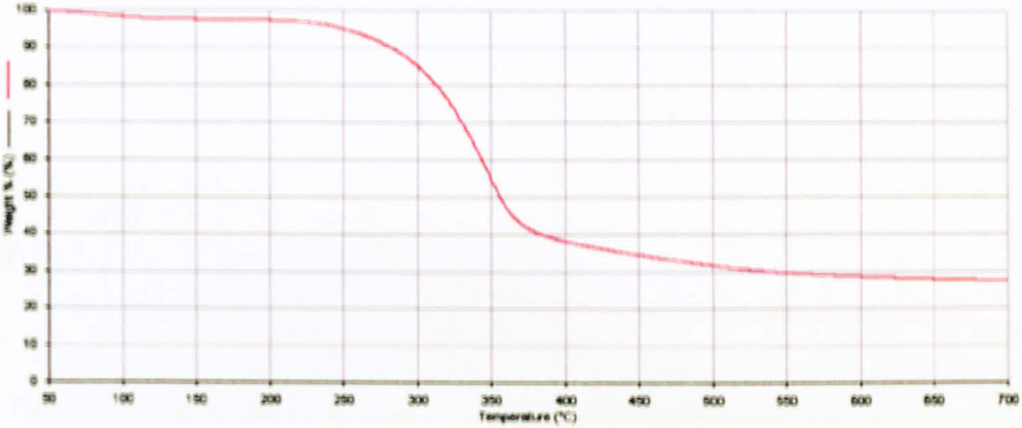


TG Curve

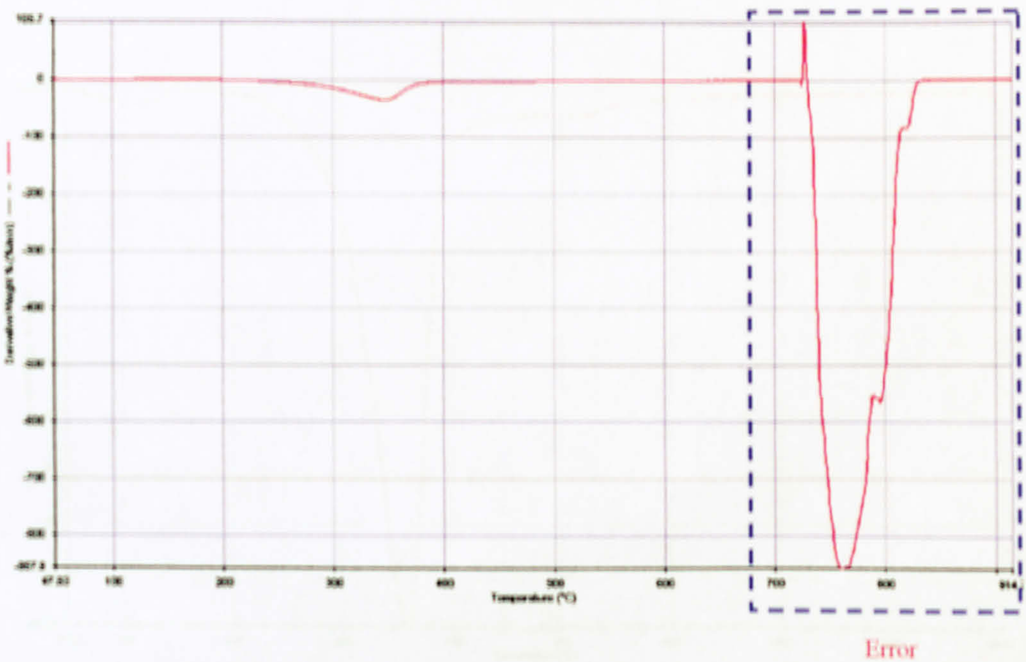


DTG Curve

## B.2 Experiment 2 (126µm-250µm - 40°C/min - 300°C)



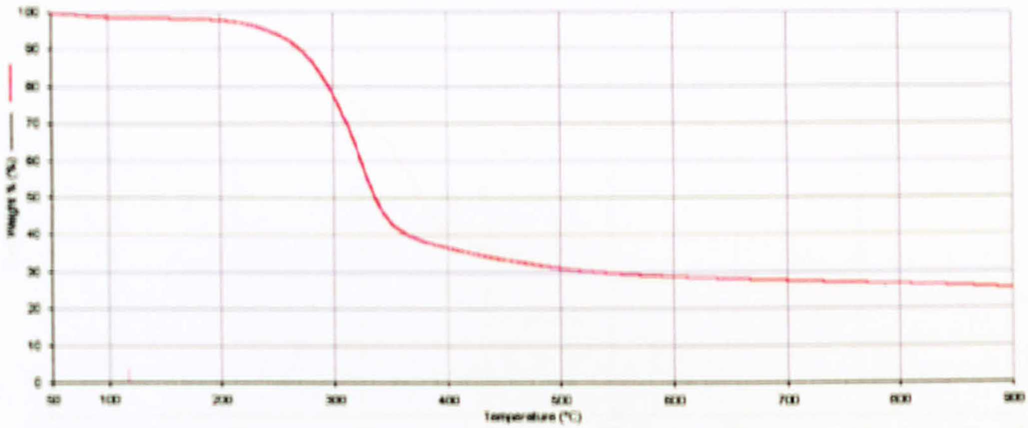
TG Curve



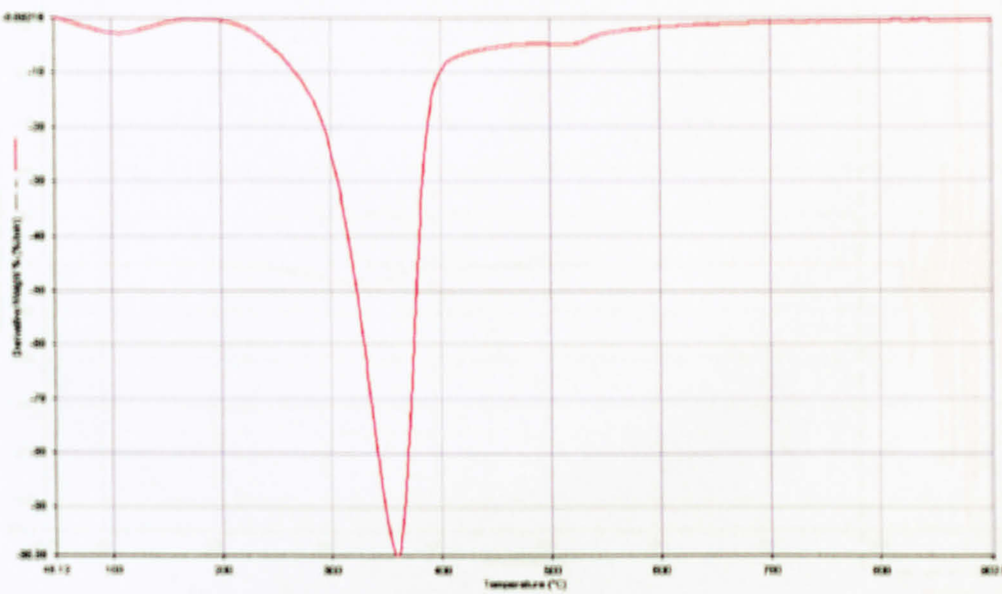

DTG Curve

Error occurred after 700°C causing inaccurate weight reading. The value needed is at 300°C, thus error occurred do not affect the result.

## B.3 Experiment 3 (251μm-500μm - 100°C/min - 300°C)

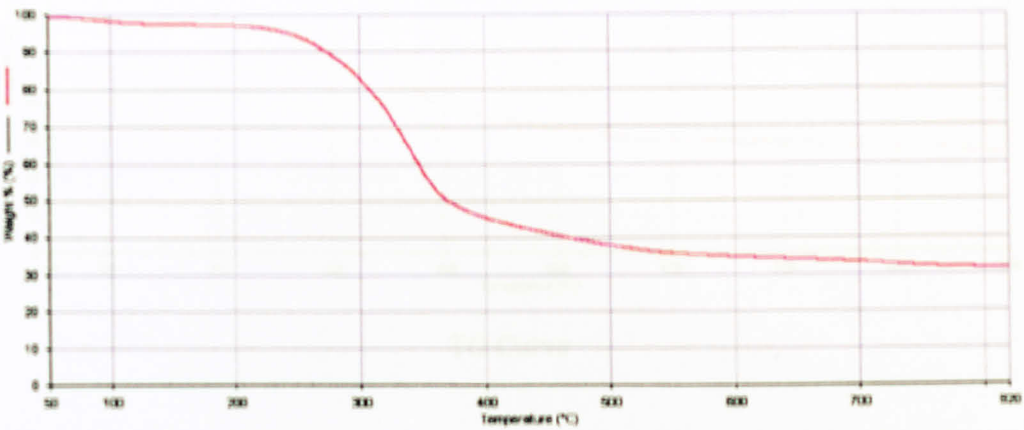



TG Curve

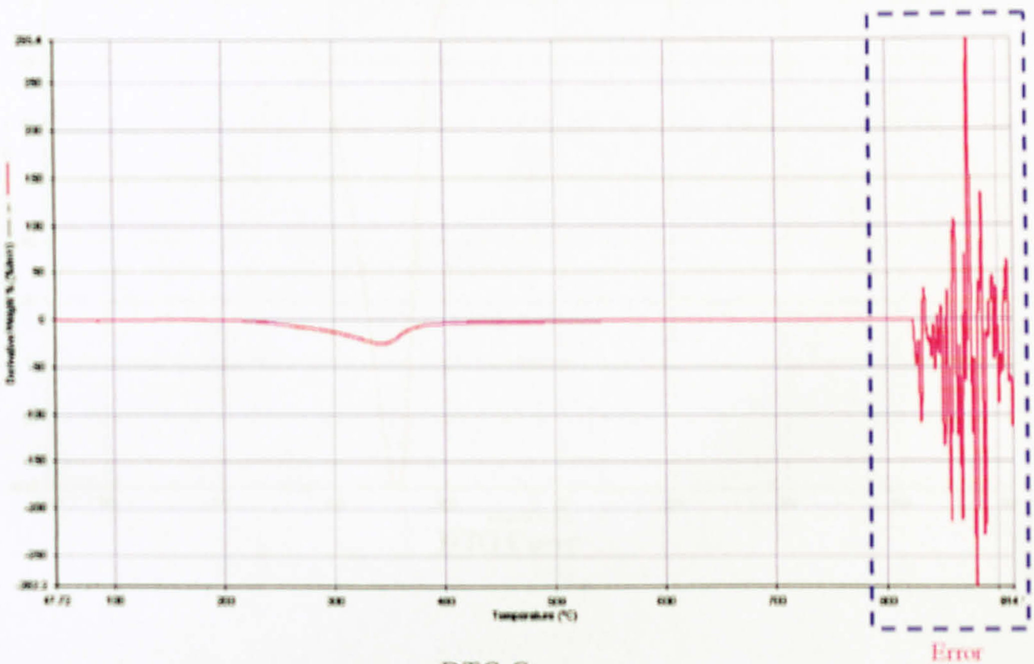



DTG Curve

## B.4 Experiment 4 (<125μm - 40°C/min - 500°C)



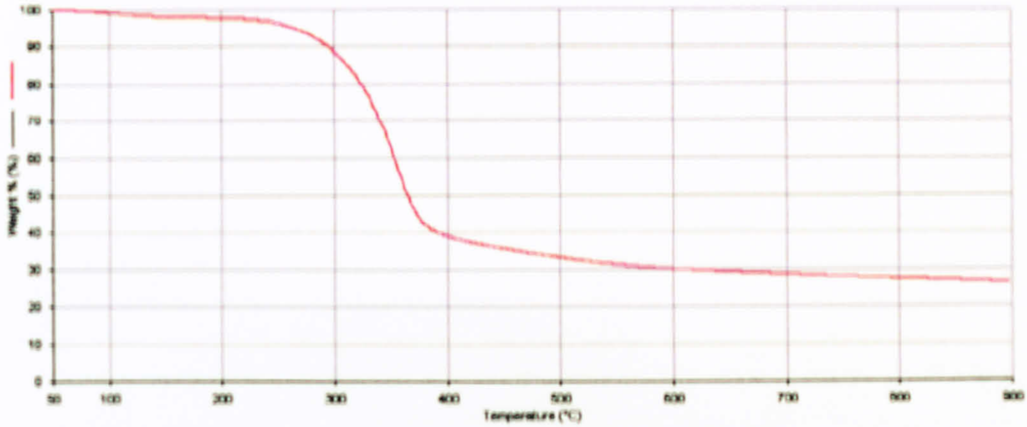
TG Curve




DTG Curve

Error occurred after 820°C causing inaccurate weight reading. The value needed is at 500°C, thus error occurred do not affect the result.

## B.5 Experiment 5 (126μm-250μm - 100°C/min - 500°C)



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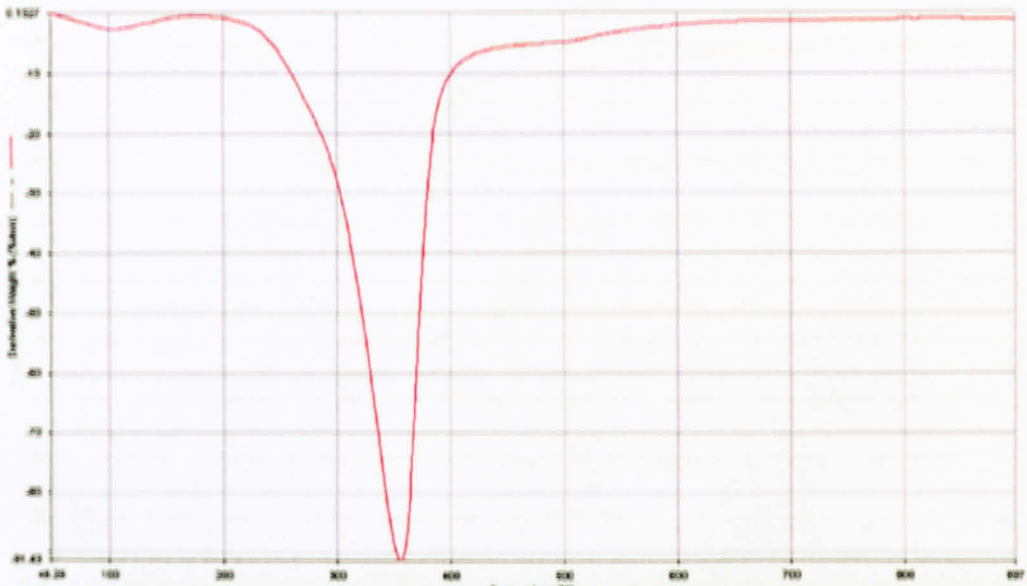
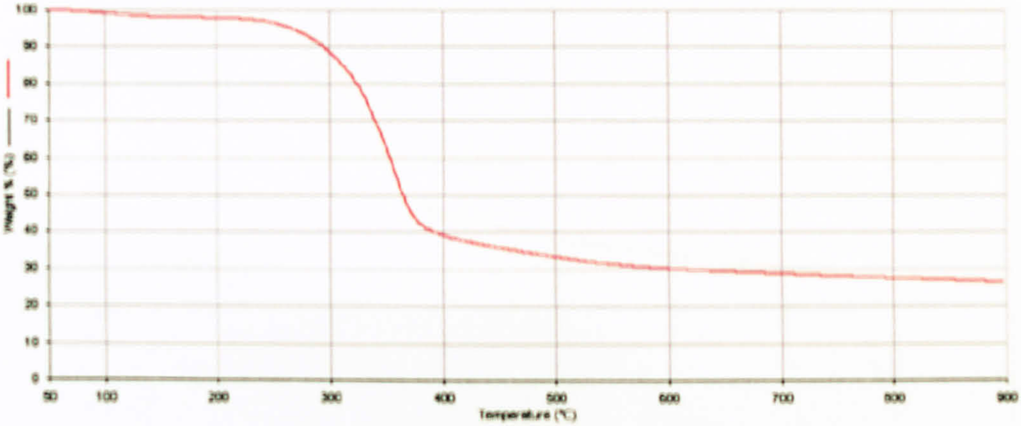
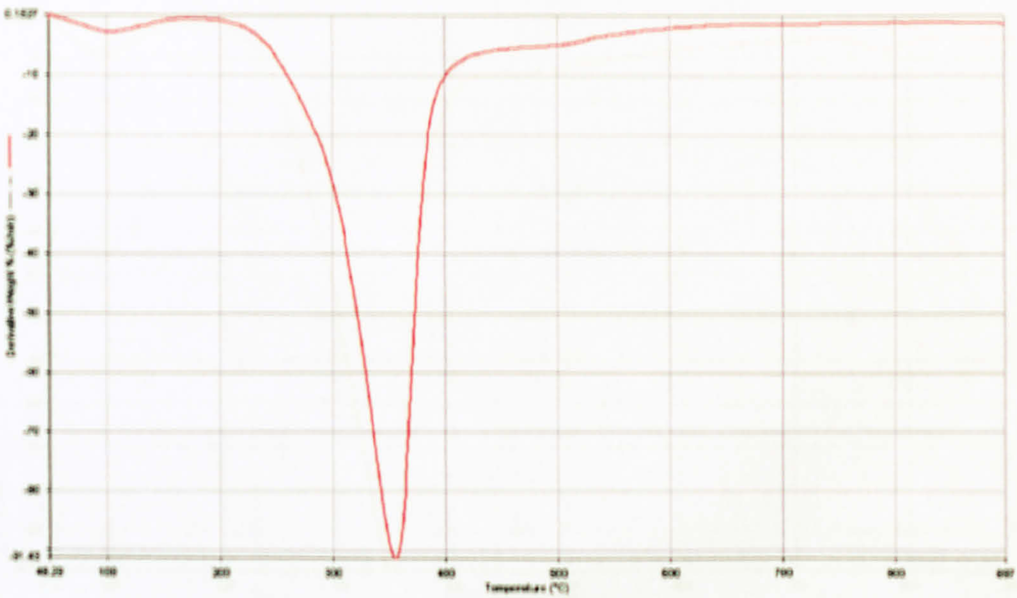


DTG Curve

## B.6 Experiment 6 (251μm-500μm - 10°C/min - 500°C)

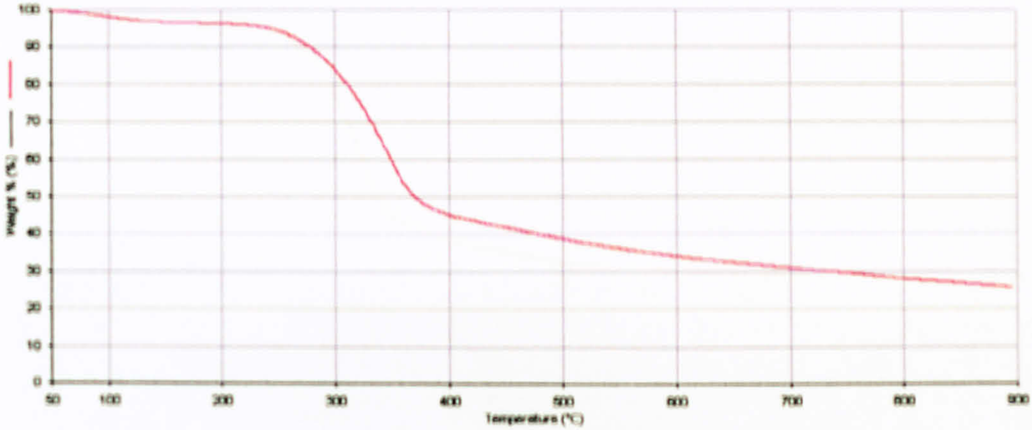


TG Curve



DTG Curve

## B.7 Experiment 7 (<125μm - 100°C/min - 800°C)



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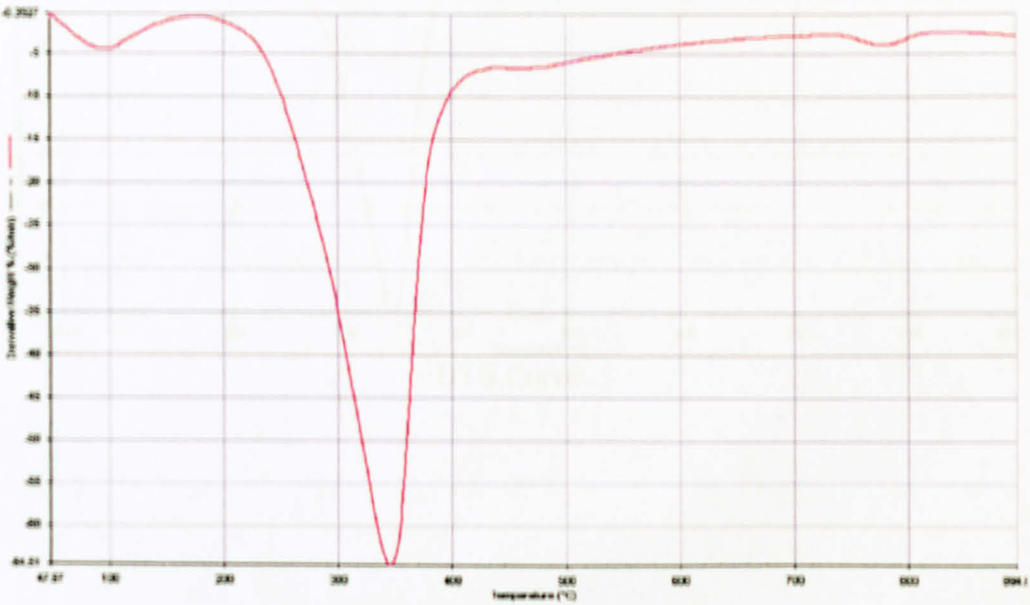
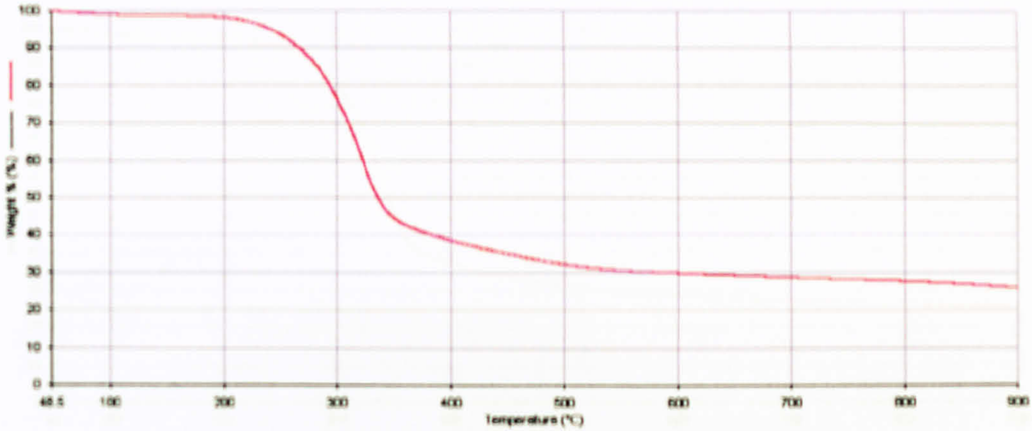
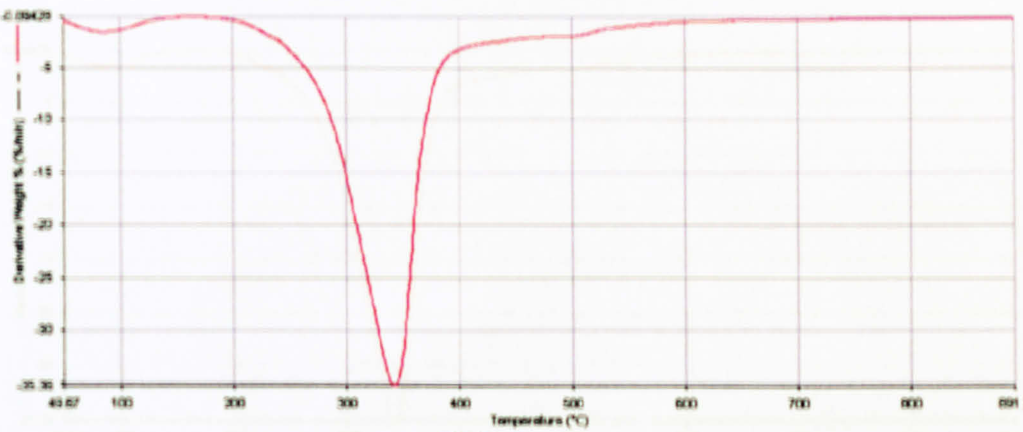


DTG Curve

## B.8 Experiment 8 (126µm-250µm - 10°C/min - 800°C)

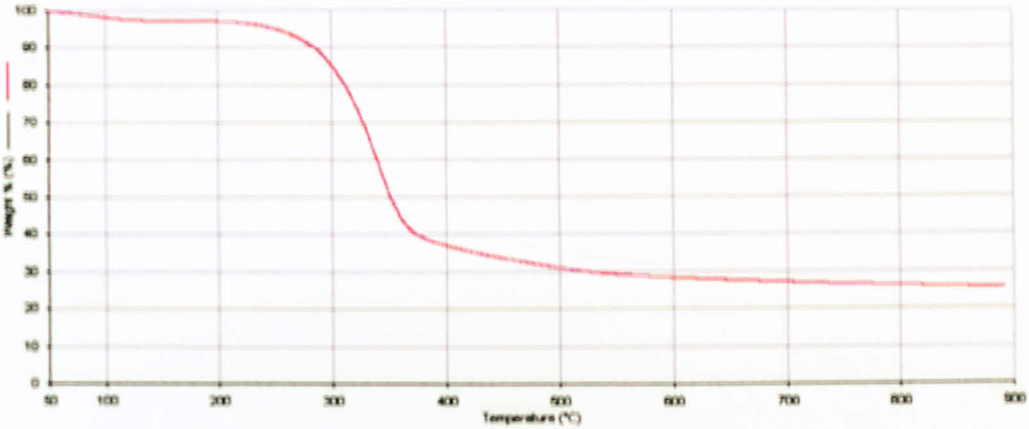



TG Curve




DTG Curve

## B.9 Experiment 9 (251μm-500μm - 40°C/min - 800°C)

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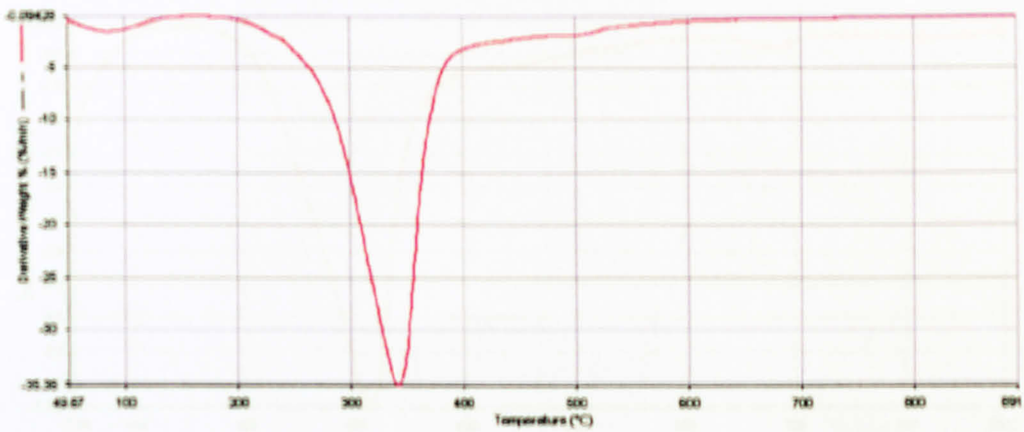
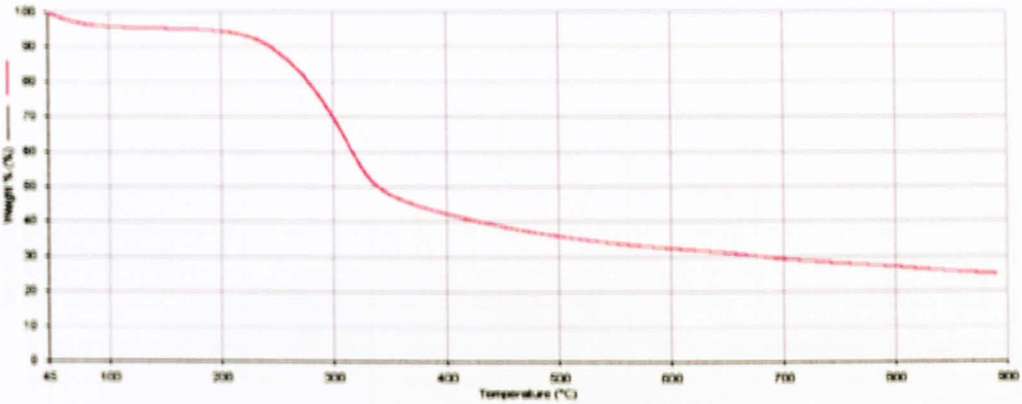
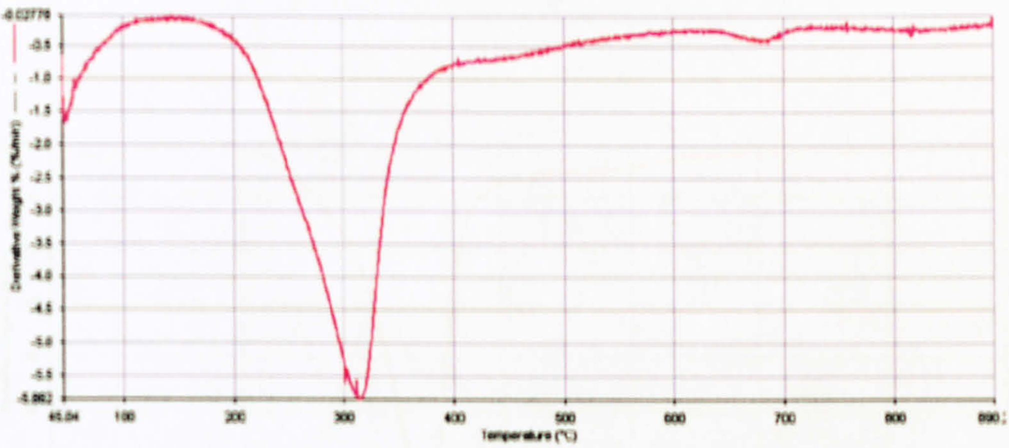



DTG Curve

## C.1 Experiment 1 (<125μm - 10°C/min - 300°C)

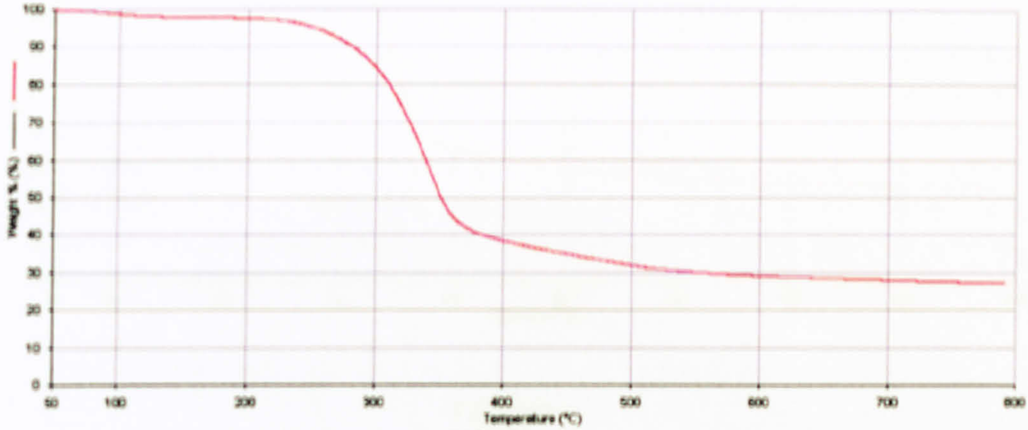



TG Curve




DTG Curve

## C.2 Experiment 2 (126µm-250µm - 40°C/min - 300°C)



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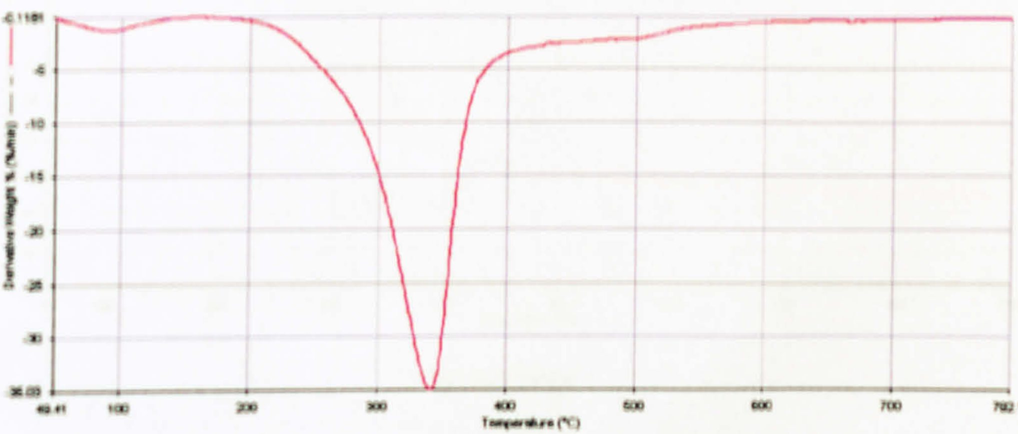
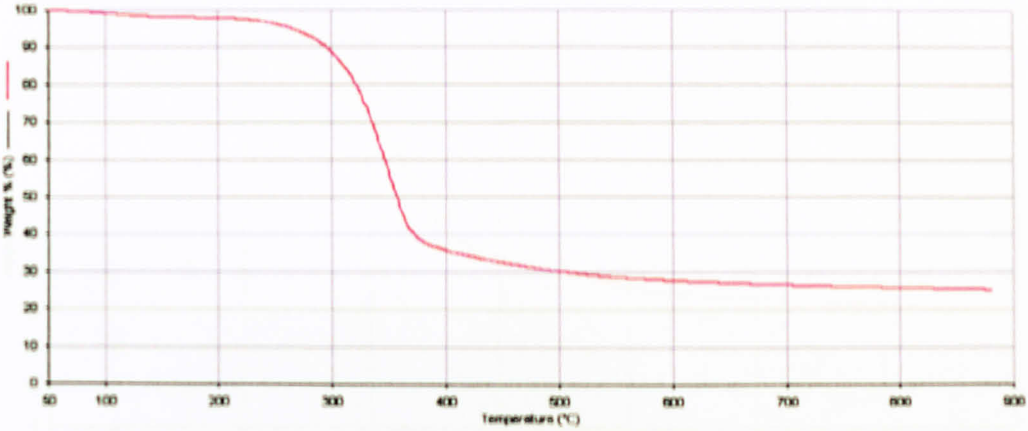


DTG Curve

## C.3 Experiment 3 (251μm-500μm - 100°C/min - 300°C)

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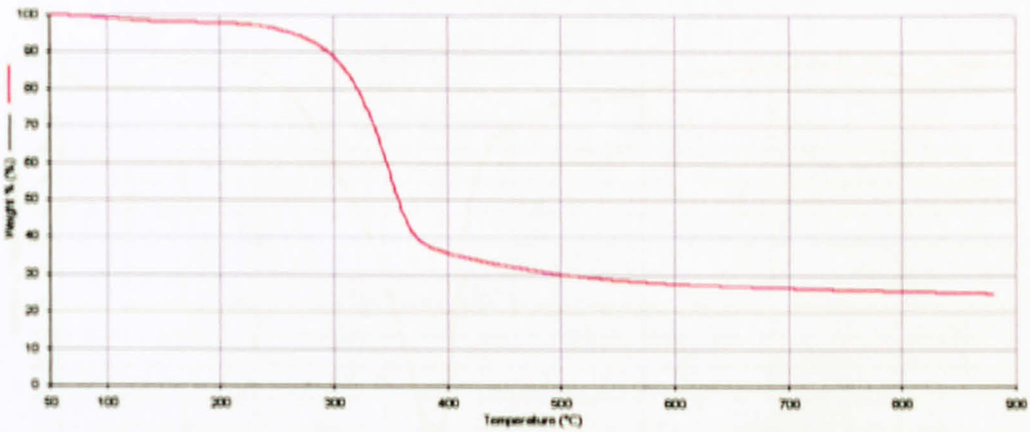


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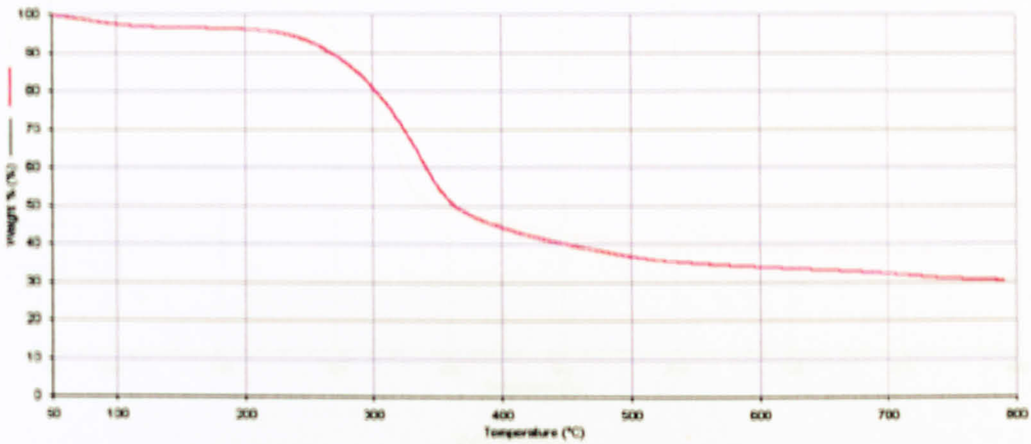


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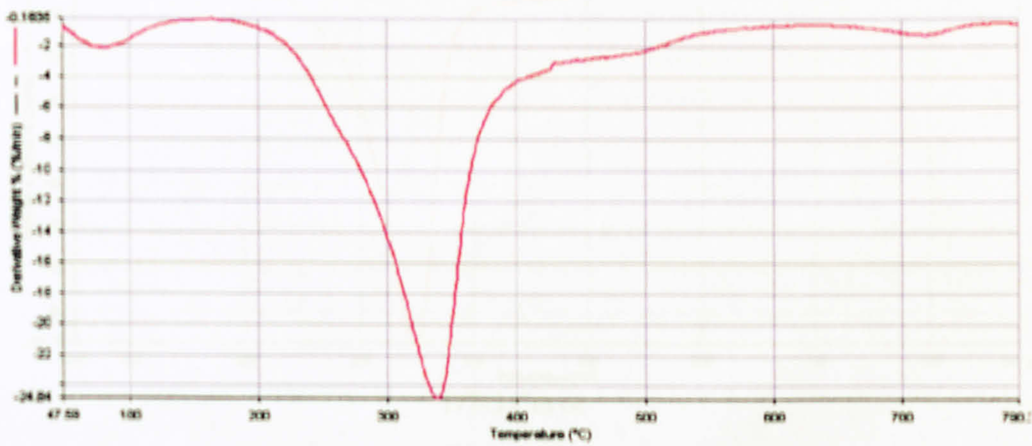


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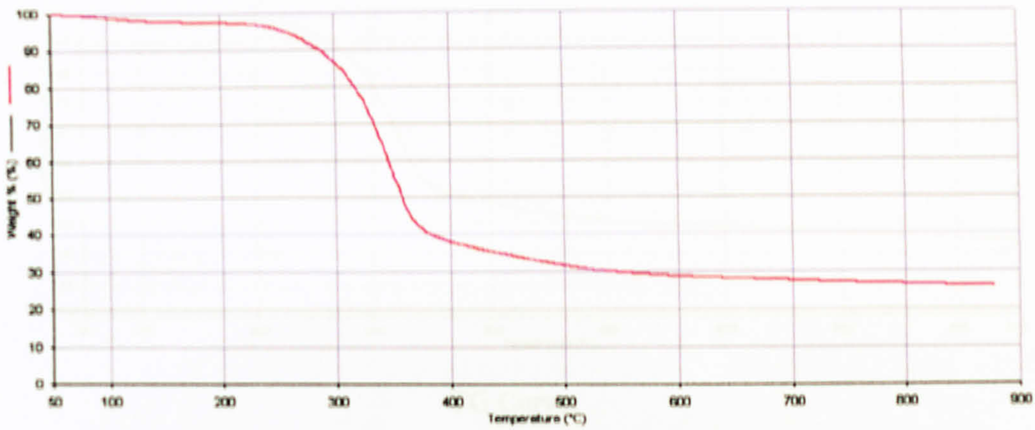
## C.5 Experiment 5 (126µm-250µm - 100°C/min - 500°C)

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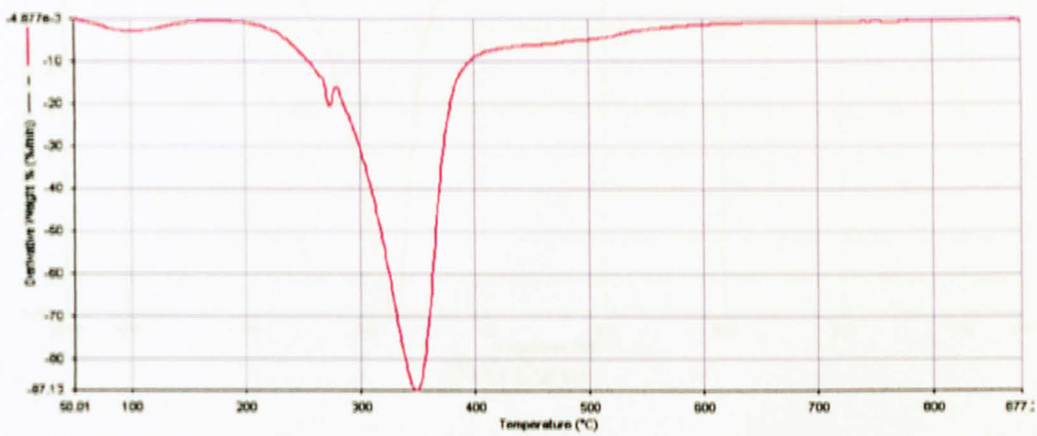


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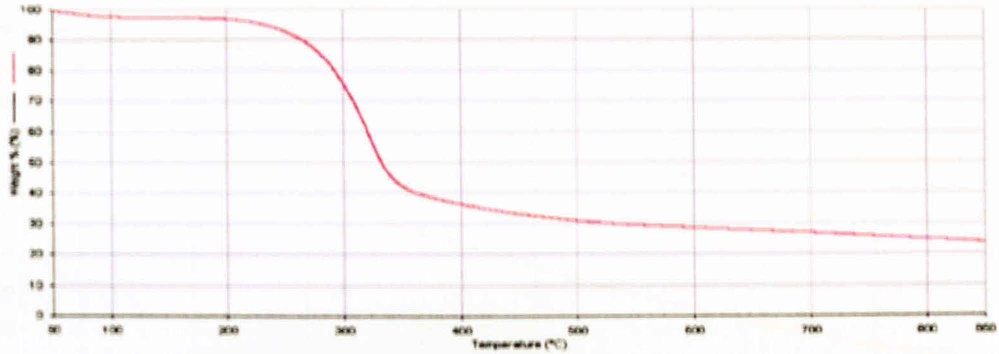


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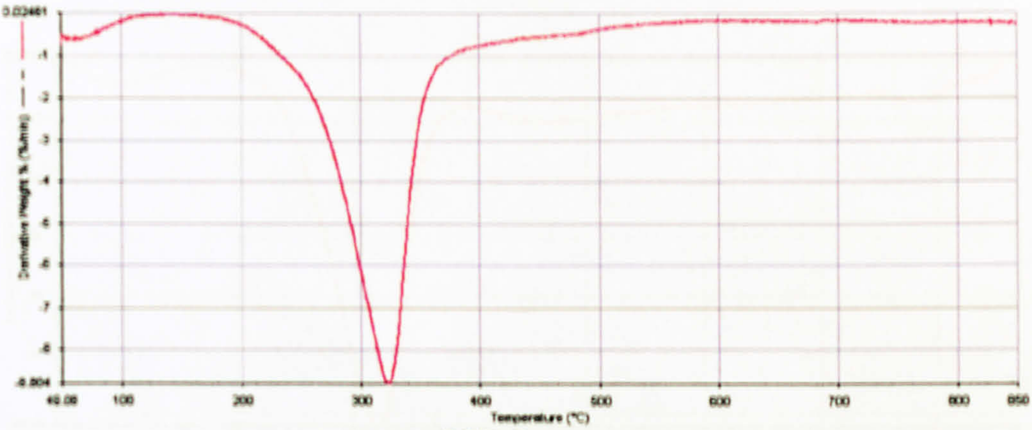
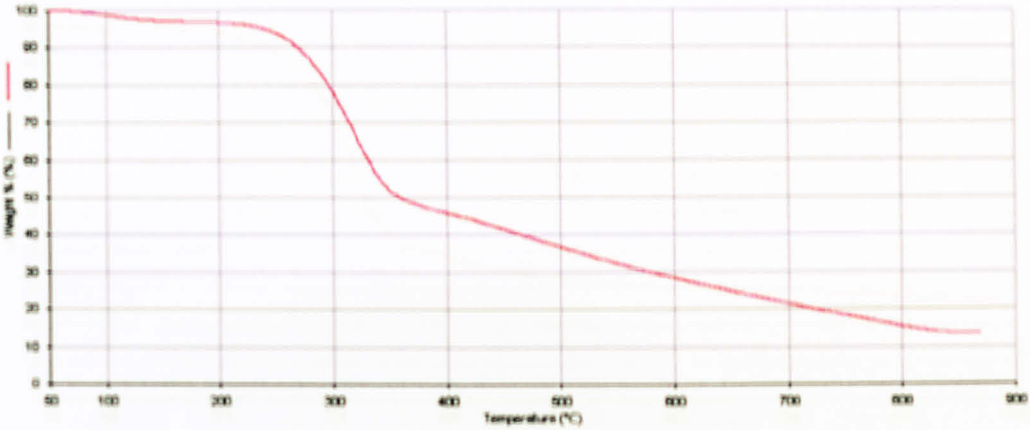



DTG Curve

## C.7 Experiment 7 (<125μm - 100°C/min - 800°C)



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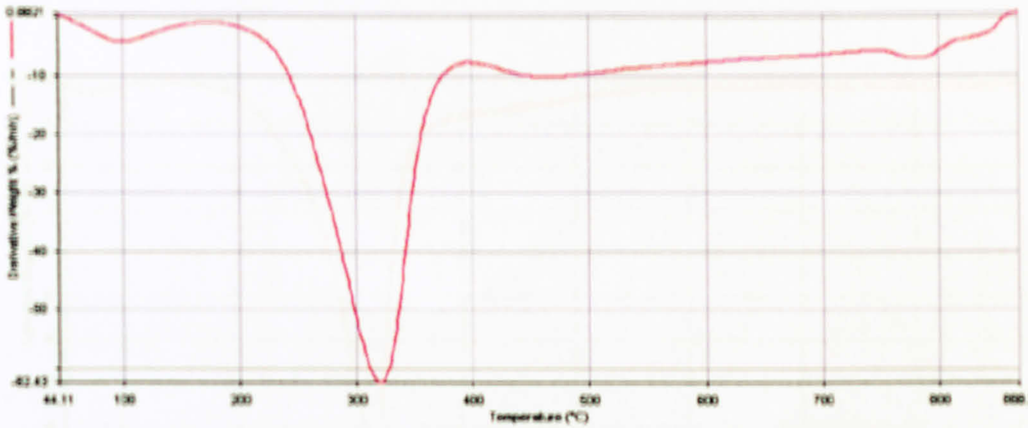
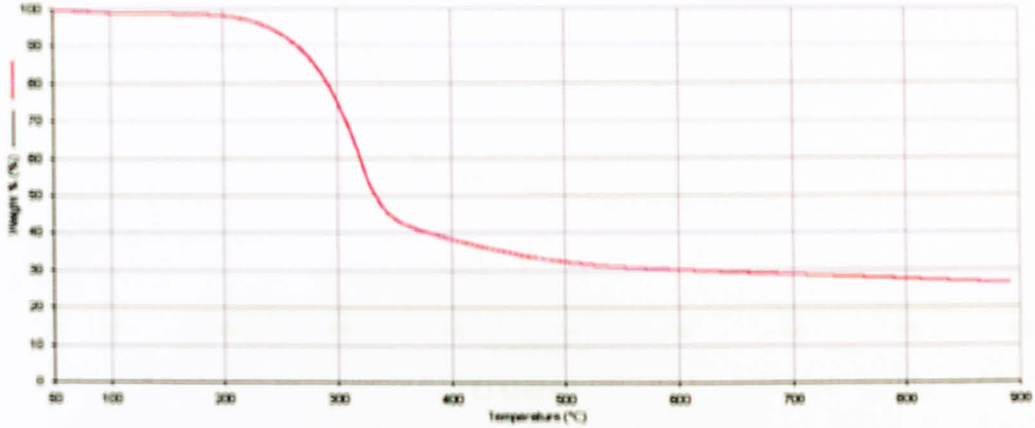


DTG Curve

## C.8 Experiment 8 (126μm-250μm - 10°C/min - 800°C)



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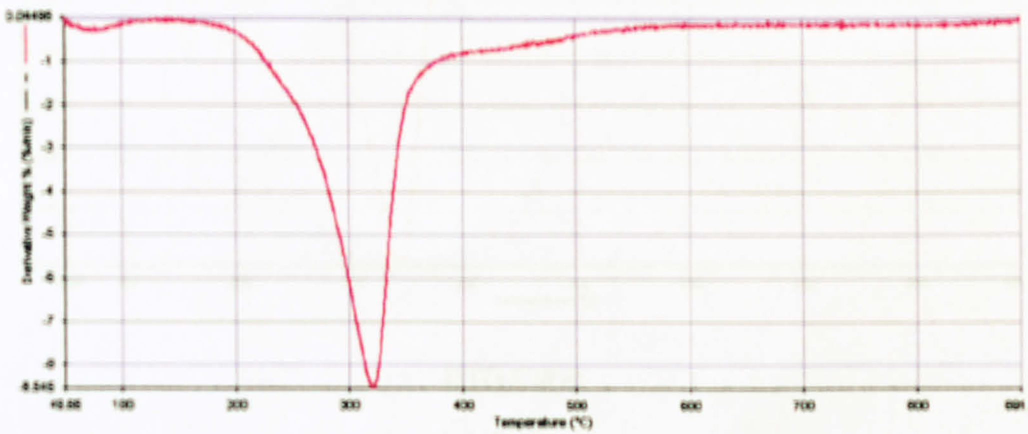
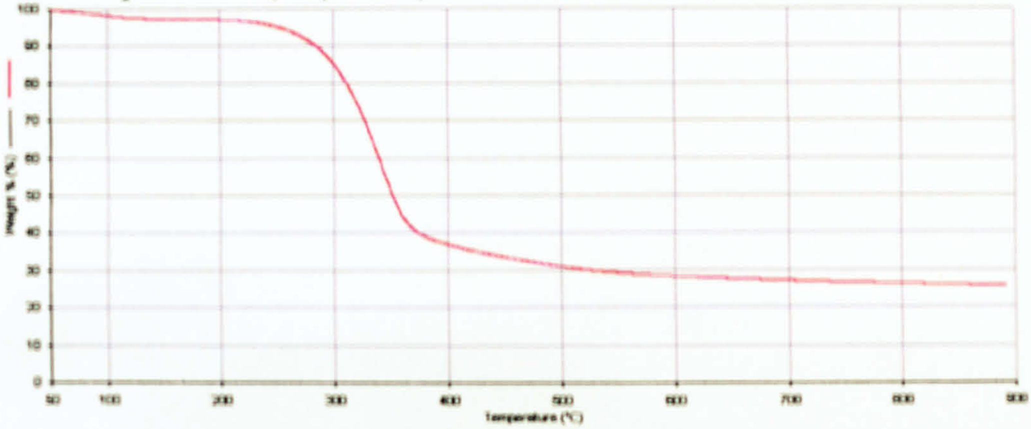


DTG Curve

## C.9 Experiment 9 (251μm-500μm - 40°C/min - 800°C)



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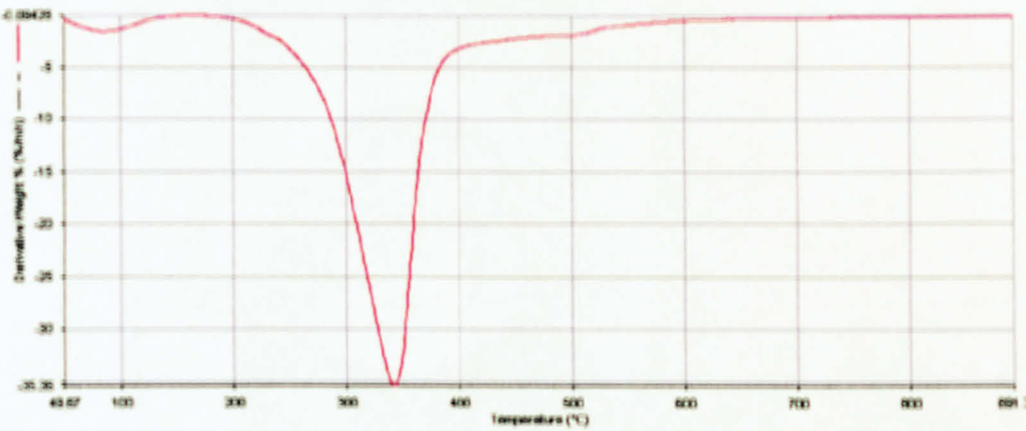

DTG Curve